An Analysis of the Schlumberger,

Fracture-Identification Log

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In fullfillment of The Ohio State University, Department of Geology and Mineralology, Senior Thesis Requirement, May 1981, Dr. George Moore, Advisor.

Respectfully Submitted,

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Purpose

This report is presented in fullfillment of The Ohio State University, Department of Geology and Mineralology, senior thesis requirement.

The identification of oil and gas reservoir fractures by the several geological and geophysical methods is important to the exploration and development of these commercial hydrocarbon reservoirs by the oil and gas industry.

The geophysical process called the Fracture-Identification Log (FIL), by Schlumberger Well Services, and the associated down-hole sensing tool is a new process, still in the basic experimental stage.

This study was undertaken by the author to understand the "FIL" geophyisical logging method, to develop an FIL data process method and to provide a geological interpretation of the results.

Acknowledgements

The author greatfully acknowledges William E. Shafer, President of Shafer Exploration Company, Incorporated, without his technical advice and guidance, this report could not have been made.

The author also wishes to acknowledge Dr. George Moore, Professor of Structural Geology and Petrology, for his assistance and patience during the writing of this report.

Objectives

1. To develop a data analysis method for a certain Schlumberger Fracture-Identification Log (FIL) recently recorded in northeast Ohio,

2. to determine the true strike of fractures, if any, oriented in the

vertical or nearly vertical plane, and

3. to Provide geologic conclusions and geophysical recommendations as a result of the investigation.

Preface

The Fracture-Identification Log (identified by the Schlumberger registered trade mark FIL) is an experimental geophysical logging tool that was developed by Schlumberger Well-Services, U.S.A. In this report the author will describe and critically evaluate a Fracture-Identification Log taken from a (3569 foot) well (on March 30, 1981) in Ashtabula County, northeastern Ohio. This log was obtained through a private geologic consulting company[1], which is also interested in the results of this study.

The importance of this study is two-fold. First, information concerning subsurface fractures in Ohio is of scientific and economic importance. Secondly, because this tool is in the experimental stages, a critical evaluation may lead to improvements resulting in a more accurate and useful tool.

Introduction

The oil industry is a high risk, high cost business. Depending on circumstances, hundreds of thousands to millions of dollars can be invested with little or no return, resulting in a so called "dry hole". Because of the enormous expenses involved in hydrocarbon search and extraction, technology is constantly being improved so that the "risk" of drilling uneconomical holes can be significantly reduced. For this reason, the oil

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[1] Shafer Exploration Company, Inc. of Columbus, Ohio.

industry is a highly competitive and dynamic industry that is constantly developing more advanced technology. Not only is technology the primary tool of the well-site geologist and petroleum engineer, but it is especially important to the exploration geophysicist. With technical aids, the exploration geophysicist predicts which areas may contain potential hydrocarbon reservoirs. Commonly, this is done prior to any drilling. However, with the advent of newer down-hole logging tools, data may now be obtained concerning the direction of possible hydrocarbon reservoirs relative to the existing well under study. This directional tool is called the "Four-Electode Dipmeter" and was developed by Schlumberger Industries and others.

The dipmeter is a wireline, down-hole logging device run in fluid-filled boreholes, that measures the dip and strike direction of beds intersecting the borehole. Before the advent of the dipmeter, such information was obtained by either coring one well with oriented core, coupled with a hole deviation survey, or drilling three related wells and correlating the zones of interest and computing true dip and strike. The Four-Electrode Dipmeter uses the same three point principle by sensing correlative bedding plane contacts at four points all of which lie inside the single borehole (usually 7 7/8" diameter). Thus, the dipmeters' most valuable function is to provide the analyst with data indicating the up-dip direction of the bedding plane(s) and therefore the potential oil and gas reservoir.

A potential reservoir formation is one with porosity and permeability (pore spaces and passages between the pore spaces). If the potential reservoir is tilted at some angle from the horizontal, the lighter, less dense fluids and gases will migrate upward (up-dip) until they reach an impermeable barrier. The less dense fluids and gases are usually the hydrocarbons in the reservoir rock. Knowledge of the up-dip direction can indicate potential sites for future drilling activity. Other uses of the dipmeter include projecting the edge of the reservoir; obtaining stratigraphic information; location and identification of faults, unconformities, and anomolous structural dips; and for obtaining general structural information.

The dipmeter detects the difference in electrical resistivity as each of the four electrodes, in the same horizontal plane and 90° apart, crosses the boundary between two zones of different electrical resistivity. This resistivity is measured in (ohms/m^2/m) or ohm-meter. Normally saline fluids of variable concentration and volumes fill the rock intersticies in and between adjacent beds. The resistivity is usually lower (conductivity is higher) in and between beds with high permeability and porosity that contain saltwater. As the dipmeter is raised past a dipping bedding plane, each of the four pads will detect this changed resistivity of identical or similar sign ("signature") at slightly different depths. The separation of curves on the resulting calibrated strip-chart (called a "log") can then be used to calculate the dip and strike of that particular bedding-plane.

The Four-Electrode Dipmeter is the predecessor of the now experimental Fracture-Identification Tool (identified by the acronym FIT). Fractures have been recognized by one single pad, or optimally by two opposing pads of the four pad sensors of the resistivity dip meter log.

Definition of Terms Used in This Report

Increment - The log scale (1/2" = 2') distance between any two adjacent horizontal lines on the FIL, and is calibrated to equal two vertical feet of borehole.

Set - The traces on the FIL of the two tool pads, one and two or the two pads three and four that are superimposed on each other.

Anomaly - A deviation of wall rock matrix values from the normal wall rock matrix values; specifically, the net separation between resistivity traces within an increment set.

Fracture - Refers only to any vertical or nearly vertical joint that is indicated by an anomaly on the FIL.

Minor Fracture - A vertical or nearly vertical joint, indicated by an anomaly, of one foot or less.

Major Fracture - A vertical or nearly vertical joint, indicated by an anomaly, that is greater than one foot.

Azimuth Hold - An FIL tool condition wherein the tool appears to have been held by a critical combination of related fracture conditions, i.e. by the simultaneous record showing anomalous opposite pad traces coupled with the nearly constant log traces of the index pad azimuth.

Azimuth Idle - That condition wherein the Fracture Identification Tool is not rotating within a fractured or unfractured increment; i.e. tool rotation has stopped as a result of some other property that is not related to fracture activity; e.g. when natural wire line rotation by cable stretch is neutral.

Two-Caliper Activity - That condition when the borehole is out-of-round, indicated by a greater extension of the caliper in the out-of-round direction.

Caliper Hold - Same as two-caliper activity, however, the caliper curve of maximum extention must be associated with the resistivity curve of least electrical resistance.

Fracture Components - are composed of the following evidence:

1) One Major Fracture
2) One Minor Fracture
3) Azimuth Hold
4) Caliper Hold

Fracture Type - Refers to a specific combination of Fracture Components.

Geological Conclusions

1. True fracture identifications associated with true strike were confined to the Devonian System. The average of the primary fractures in the Devonian were oriented N 12° W. The average of the secondary fractures in the Devonian were oriented N 58° W (figures 2 and 3).

2. The fractures in the upper Devonian may have been caused or enhanced by the adjacent contact with and subsequent effect of isostatic (continental) glacial loading, with the force of the isostatic loading dissapating with depth.

3. There is a considerable variation between the number of true and apparent fractures contained in the various Devonian and Silurian formations (Table 2).

4. The amount of fracure evidence does not appear to correspond directly to gross formation lithology (Table 3). Matrix conditions, that may contribute to fracture development within a lithologic unit are:

a) Porosity.
b) Permeability.
c) Amount and types of accessory minerals present.
d) Amount of shale present.
e) Type and kind of intergranular cementation present.

Thin-section investigation, core analysis and certain electric logs would help to clarify the association, if any, between the rock matrix condition and matrix fracture suceptibility.

5. The Devonian, Delaware Limestone contains a greater quantity of fracture evidence, relative to adjacent formations and also other formations with similar lithologies. The author can offer no explanation for this anomalous phenomenon.

6. The Silurian, Oldham (the driller's "Packer Shell") has obvious economic significance. The "Packer Shell" is believed, by many investigators, to

function as an impermeable barrier (cap rock) to the hydrocarbons contained in the "Clinton" sandstone below. The "Packer Shell" observed within this investigation had no fracture evidence (Table 2).

7. The Silurian, Grimsby Cabot Head sandstone (the driller's "Clinton") has economic importance. It often contains commercial hydrocarbons. Eight percent of the "Clinton" interval observed within this investigation had fracture evidence, however, with no identifiable strike (Table 2).

8. The gross Devonian interval contained 39% fracture evidence.

9. The gross Silurian interval contained 22% fracture evidence. The author believes that the fracture frequency difference (17%), between the Devonian and Silurian intervals, may be caused by the apparent increase in gross lithic competency of the Silurian formations and the effect of continental glaciation on the Devonian.

10. A relationship (factor) may exist regarding the number of fractures sensed by the tool in any given zone and the number of fractures actually intersecting the hole within the same zone.

Geophysical Recommendations

The Fracture-Identification Log (FIL) and tool is a remarkable electro-mechanical sensing device. The tool senses and sends a quantity of data within a small space and under great hydrostatic pressures. However, there are certain (constructive) criticisms of the FIL tool that can be made as a result of this study.

1. The multiple out-put of the tool can best be handled by computer. The

author understands[1] that this conversion to computer is in process.

2. The tool can only sense (except in one special case) one fracture plane per increment at a time and within the special provision that the fracture plane pass through the diameter of the hole within the rotational frequency of the tool. Obviously the tool may very well miss many actual fractures in the hole.

3. The natural rotation of the tool in the hole was observed, upon occasion to stop (the "Azimuth Idle" case) for natural reasons other than the presence of fractures. The ceasation of rotation because the cable dynamics are neutral may 1) cause misleading fracture related inferences and 2) may cause the tool to miss a number of actual fractures, and again, effect the geologic interpretation.

The tool should be made to rotate (scan) at a constant rotation per foot.

4. The FIL tool throughout an appreciable portion of this analysis was apparently not up to proper sensitivity. The resistivity pad number three indicated a considerably greater amount of fracture evidence than any of the other sensing pads. This effect would, and probably did reduce the number of basic fracture evidence identifications and the true strike of fractures identified. In defense of this observation, it is properly assumed that fractures within a borehole are randomly distributed around the walls of the borehole as the FIL tool rotates. Fractures, therefore, should be detected equally by all four of the electrical resistivity sensing pads. This was not the case however, (refer to the data sheets in the appendix). This particular problem can be corrected by the instrument operator. The loss of equal sensor pad sensitivity, of course, reduces the effectiveness of the instrument, the

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[1] Personal communication W. E. Shafer, May 1981.

interpretation effort and the basic utility of the tool.

5. Although only vertical or nearly vertical fracture evidence was noted and recorded in this study, it became obvious to this investigator that fractures that were present and not approximately vertical would be difficult if not impossible to identify since no identifiable recorded signal, "signature" could be assigned to any given fracture. It would be difficult to systematically identify inclined fractures from the background "noise". The tool should be equipped to better identify inclined fracture planes.

6. Some evidence of horizontal or bedding plane fractures were noted and may be a useful observation and base of study in the future.

The Basic Study

The (FIT) Fracture-Identification Tool Description

The (FIL) is the output of the experimental (FIT), which shows the four dipmeter curves. These curves can indicate the presence of fractures and can be recorded as separate resistivity logs of the four sensor pads, that is, in the dipmeter log format, or the curves can be run with either opposite or adjacent pad curves superimposed. The physical principles upon which the dipmeter can detect bedding planes is the same principle upon which the FIT detects the fluid that fills an open fracture. The saline fluids in the fractures usually have much less resistivity than the rock in which the fracture occurs. The focused resistivity FIT device, is mounted with sensors pressed against the rock face of the borehole. The FIT is cable-suspended and tends to rotate in the hole, as do almost all down-hole logging tools. Low resistivity readings across the same fracture can be detected by all four pads in sequence as the tool rotates. These four resistivity pads, mounted in a plane 90° apart, work in conjunction with four other important instruments within the same tool. These are 1) the azimuth sensor on the number one pad, 2) the two, hole-diameter (caliper) sensors, 3) the hole-deviation from vertical sensor and 4) the hole-deviation azimuth sensor. The out-put on the FIL of these sensors repectively are called; 1) the azimuth curve, 2) the two, hole-diameter caliper curves, 3) the deviation curve and 4) the relative bearing curve.

The azimuth curve indicates the magnetic north direction of the number one pad. The two, hole-diameter caliper curves, each recorded by one pair of arms, detect "out-of-round" holes. In fractured zones, the borehole can tend to get "out-of-round" becoming slightly elongated in the direction parallel to the strike of the fractures. This effect tends to impede or eliminate tool rotation through the fractured zone as indicated by the azimuth. Both the azimuth-trace and two caliper, hole-diameter, traces aid in the recognition of fractured zones. The deviation curve indicates tool inclination from the vertical. The relative bearing curve indicates the bearing direction of the number one pad from the high side of the borehole. The four resistivity curves, the azimuth-trace, the two caliper hole-diameter curves, the deviation curve and the relative bearing curve are all recorded continuously and simultaneously as the tool is raised in the hole. The hole-deviation curve and the relative bearing curve are useful only in directional boreholes or deviated boreholes. Consequently, these sensors had no direct utility in the vertical borehole studied, except to indicate that the hole was in fact vertical.

The Study Well

The FIL that was studied in this report came from a well in Ashtabula County, northeastern Ohio. Since this well may have some residual proprietary significance, exact location information cannot be given. The well is vertical and the log was taken from 1190 feet to 3568 feet below the "Kelly Bushing" (K.B.) in the derrick floor. The top of the interval includes the lower 712 feet of the Ohio Shale, the bottom of the interval includes the upper 204 feet of the driller's Silurian, "Clinton" formation. All intervening formations (Table 2) are included, except the Salina salt section (F-A Units).

A Detailed Description of the FIL Log

(See Plate 1)

The strip chart, more commonly called the log, produced by the tool, consists of two separate log grids with corresponding horizontal lines indicating each two feet of vertical hole depth. The left-hand log grid contains three curves: the relative bearing, hole Deviation and azimuth. As previously mentioned, relative bearing curve and the hole deviation curve are useful only in non-vertical holes (directionally drilled) and therefore were not useful in the vertical hole studied. The scale begins on the second vertical line from the left, which represents 0°. Each of the remaining 9 vertical lines represents 40° to give a total of 360°. The azimuth is the angle between magnetic north and the number one pad. Depending on the position of the azimuth curve on the grid, the degrees east or west of the number one pad can be determined at any depth.

The log grid on the right is the larger of the two and contains the two, hole-diameter caliper curves and the four resistivity/conductivity curves that correspond to each of the four pads. The four pads, mounted in the same horizontal plane and 90° apart are numbered clockwise one through four. When the number 1 pad is oriented to magnetic north (azimuth 0° or North South), the number 2 pad is due east, the number 3 pad is due south and the number 4 pad is due west. On the FIL grid the resistivity curves of pads 1 and 2 are superimposed on each other. Likewise, the resistivity curves of pads 3 and 4 are superimposed on each other. On the right-hand FIL grid, therefore, there are two separate sets of curves with each set containing two superimposed resistivity curves. The set to the left of this grid contains the curves of pads 1 and 2 with the set to the right containing the curves of pads 3 and 4.

To visually differentiate between the two superimposed resistivity curves, the curves of pads 1 and 3 are represented by solid lines whereas the curves of pads 2 and 4 are represented by dashed lines.

On the FIL grid, resistivity decreases to the left. As previously mentioned, in a fracture full of saltwater a decrease in resistivity usually occurs relative to the surrounding rock. At any one place in the hole, the pad or pads that lie on a fracture will be represented by a curve that is further to the left than the curve(s) that represent the pad or pads that are in contact with the surrounding rock wall.

Also represented on this same right hand grid are the two, hole-diameter caliper cuves. All four of the pads are "spring loaded" and press against the walls of the hole. The amount of extension of opposite resistivity pads (that is pads 1 and 3 and pads 2 and 4) is continually recorded and ploted on the FIL grid as the tool is raised in the hole. The horizontal scale assigned to the caliper curve is 1/4" = 2". There is no horizontal scale for the resistivity out-put curves. However, exact values of resistivity are not important for fracture identification. A "separation of the curves" within a set, indicates a fracture. The pad corresponding to the "left-most" curve, within a set, is the pad on the tool that has detected the fracture.

As previously mentioned, the tool is cable suspended. Unimpeded, the tool tends to "unwind" at the end of the cable as a natural property of cable stretch and the "lay" or weave of the multi-strand cable. This "unwinding" motion or rotation of the tool allows the four resistivity pads to "scan" the wall of the borehole as the tool is raised in the hole. Unimpeded, the tool was observed to rotate approximatly 360° every 200 - 300 feet (rotation is also dependent upon the amount of free suspended cable, fluids in the hole, up hole velocity, etc.).

Fracture Orientation

In the case of vertical or nearly vertical fractures, one of the four pads may become caught or "lodged" in a fracture, thus stopping the rotation of the tool. As the tool is raised in the hole, the "lodged" pad will tend to travel the length of the vertical fracture until the fracture ends or until the tool becomes "dislodged" and begins to rotate again. If the vertical borehole diameter intersects a nearly vertical or vertical fracture, the (left-most) resistivity curves produced by two opposite pads indicate the true strike of the fracture which can be computed from the azimuth curve. If the azimuth holds where, (at the same depth-point in the hole) a separation of one of the resistivity curve "sets" occurs, a nearly vertical or vertical fracture has been detected and the apparent strike of this fracture may be determined.

If either curve corresponding to pad number one or pad number three shows the increase in conductivity, the strike of this fracture can be determined by reading the azimuth-hold degrees from the grid. The strike is given in degrees either east or west of magnetic north. If the curves corresponding to pad two and/or pad four shows a decrease in resistivity, a correction of 90° must be added or subtracted from the bearing direction indicated by the azimuth curve on the FIL. This is done so that the direction of the detecting pad can be corrected in terms of the number one pad. The correction for magnetic declination must also be made to correct all bearings to true north.

A hole drilled through a fracture zone can become out-of-round, with the long axis of the hole corresponding to the strike of the fractures. If this out-of-round hole occurs with pads on opposing caliper arms, (which indicate the long axis of the hole) and a decrease in resistivity is also indicated upon the same opposing pads, the strike of the fractures can be determined. In the ideal case, the FIL curves would indicate an increase in conductivity between two opposing pads, a non-rotating FIT, and an out-of-round hole, with the long axis corresponding to the pads showing increased conductivity.

Other Logs Used in This Report

Lithologies within the study borehole were determined by analyizing[1] the associated Schlumberger, Bulk Density and Gamma Ray Logs[2]. It is not within the scope of this report to discuss the physics and mechanics of these logs. However, pertinent data from the analysis of these logs (i.e. depth to top of the formations and gross formation lithology) is included in this report, Table 3.

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[1] Personal guidance by W. E. Shafer, petroleum geologist, Shafer Exploration Company, Inc., May 1981.

[2] Schlumberger Industries.

Analysis Method

Fracture Ranking System

The approach taken in analyzing the FIL was to be as systematic and objective as possible, much the same way in which a computer program would be developed to analyze the data. To achieve this, a system of "ranking" was devised, in which every combination of fracture components were assigned a unique rank. A relative scale of importance of fracture-type was also accomplished by this ranking system.

The rank of a fracture is determined by adding the specific, assigned numbers given to the fracture components present within a given increment.

The number that is assigned to each "fracture component" is based on its relative importance to the other "fracture components".

Table 1

Fundamental Rank Assignments

Fracture Components	Assigned Number
One Major Fracture	4.0
One Minor Fracture	3.0
Azimuth Hold	.6
Caliper Hold	.5

Table 1-A

Rank By Fracture Components

Combinations of Fracture Components	Rank
One minor fracture	3.0
One minor fracture and caliper hold	3.5
One minor fracture and azimuth hold	3.6
One major fracture	4.0
One minor fracture, azimuth hold and caliper hold	4.1
One major fracture and caliper hold	4.5
One major fracture and azimuth hold	4.6
One major fracture, azimuth hold and caliper hold	5.1
Two minor fractures	6.0
Two minor fractures and caliper hold	6.5
*Two minor fractures and azimuth hold	6.6
One major fracture and one minor fracture	7.0
*Two minor fractures, azimuth hold and caliper hold	7.1
One major fracture, one minor fracture and caliper hold	7.5
*One major fracture, one minor fracture and azimuth hold	7.6
Two major fractures	8.0
Two major fractures and caliper hold	8.5
*Two major fractures and azimuth hold	8.6
*Two major fractures, azimuth hold and caliper hold	9.1

* Components required to determine vertical fracture true strike azimuth.

Certain criteria were established when special cases were encountered:

1) Minor fractures have been excluded if the individual traces were not discernable.

2) Major and minor fractures have been excluded, if the resistivity trace set separation was not significant.

Through the use of the fracture components and their assigned numbers (table 1), the specific combination of fracture components can be readily determined by noting the rank, (Table 1-A).

Data Sheet

A data sheet (figure 1) was designed to assist in the ranking of fracture(s). On the data sheet, two adjacent horizontal lines were alotted to each increment. The top line (line one from here on) will be described first:

Sheet

DEPTH Comments	1	2	3	4	AZIMUTH HOLD	BEARING	CALIPER	RANK
Line 1								
Line 2								
Line 1								
Line 2								

Figure 1

Data Sheet

In the far left-hand column,figure 1, under the DEPTH heading, the interval footage below K.B. was recorded. This interval represents 1) the interval of either azimuth hold (AZIMUTH HOLD), or azimuth idle (AZIMUTH IDLE), 2) the interval of No Significant Fracture activity (NSF), 3) the Interval Not Recorded in the borehole (INR) and 4) the increment. The comments, (i.e. NSF), are recorded on the lower of the two lines (line two from here on). No comment is recorded in the case of the (two foot) "increment".

The depth to the top of a specific formation is recorded on line one with the formation name on the lower line. The numbered columns refer to the traces showing decreased resistivity anomalies. Line one is reserved for minor fractures and line two is reserved for major fractures. If an Azimuth Hold was apparent, a check (/) was placed on the line two in the appropriate column. The Bearing of the Azimuth Hold was recorded on line two in the appropriate column. If an azimuth idle was observed, no check ( ) was placed in the Azimuth Hold column. If the caliper hold has been observed, a check (√) was placed on line two. The rank has been determined within each increment by adding the assigned numbers of the fracture components present.

Graph and Table Descriptions

In order to better interpret the results of the data sheet, two types of graphs are presented.

The Histogram

Histograms (appendix 1) have been constructed that readily indicate the total footage of each rank (fracture type) found in each formation. The two caliper showed virtually no activity throughout the FIL. In the two areas where caliper activity was observed, azimuth hold appeared to coincide. For this reason, the fracture types involving two-caliper activity were omitted from the histogram except in the case where it may have been observed in conjunction with fractures and azimuth hold. Those ranks omitted from the histogram include ranks 3.5, 4.5, 6.5, 7.5 and 8.5. The total footage of rank 8.6 (strike of fracture known) within a formation is represented in red on the histogram. The total footage of rank 7.6 (strike of fracture known), present in a formation is represented in purple on the histogram. All other ranks are represented in blue on the histogram.

The FIL only represents the lower 702 feet of the total 1852 feet of the Ohio Shale and the upper 180 feet of the total Clinton Sandstone. Therefore, the histograms for these formations do not represent the entire formation.

Tables

Table 3 was compiled to indicate (from left to right): 1) the depth to each formation top, 2) the thickness of each formation, 3) the formation name, 4) the gross lithology present in the formation, and 5) the percentage of the gross lithology present in the formation[1].

Table (2) was compiled to indicate the percent of each formation fractured, as recorded by the FIL.

Polar Coordinate Graphs

Polar Coordinate graphs (figure 2 and 3) have been constructed, to represent the total vertical length and strike of those fractures with a rank of 7.6 and 8.6 indicated by the histograms[2].

On each polar coordinate graph, the heavy concentric circles represent two feet of fracture. The vertical borehole range of vertical fracture strike directions have been indicated near the corresponding rosette[3].

Horizontal Fractures

Near horizontal to horizontal fractures cannot be discerned from bedding planes on the FIL and consequently have been excluded in this study. A section of the graph has been reproduced (Plate II) with near horizontal to horizontal fractures/bedding planes, as indicated by the resistivity curves.

End of Narrative

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[1] Gross lithology, percent lithology present in each formation and formation tops were obtained from Bulk Density and Gamma Ray logs of this borehole.

[2] A separate polar coordinate graph has been constructed for each rank that indicates fracture strike.

[3] The graphical representation of the true strike azimuth of the measured vertical fractures.

Table 2

The amount of fracture evidence within each formation as shown by the FIL

	Formation	Percent of Formation That is Fractured	True Fracture Strike
	Ohio (Lower) Shale	288/702 = 41.0%	N 54° W N 11° W
	Olentangy	54/136 = 39.7%	
	Delaware	40/45 = 88.9%	
39%	Columbus	50/113.2 = 44.2%	
	Bois Blanc	2/55.8 = 3.6%	
	Oriskany	0/6 = 0 %	
	Helderburg	16/93.5 = 17.1%	
	Bass Island	2/37.7 = 5.3%	
	G - Unit	56/180 = 31.1%	
	F - A Units[1]	NA/374.6 = NA	
	Green Field Guelph	8/62.2 = 12.9%	
22%	Lockport	72/345.2 = 20.9%	
	"Newburgh"	40/68 = 58.8%	
	Rochester	10/18 = 55.6%	
	Packershell	0/24 = 0 %	
	Clinton (Upper)	14/180 = 7.8%	

[1] F - A Units were not recorded by the FIL.

NA: Not Available.

Table 3

Formation Characteristics of the Study Borehole
(As obtained from Bulk Density and Gamma Ray logs of the study borehole)

DEPTH TO FORMATION TOP	THICKNESS	FORMATION	LITHOLOGY	PERCENTAGE
----	Lower 702'	Ohio Shale		
			Shale	100%
1902'	136'	Olentangy Shale		
			Shale	100%
2038'	45'	Delaware Limestone		
			Limestone, sandy	7%
			Limestone	71%
			Limestone, Dolomitic	21%
2083'	113.2'	Columbus Limestone		
			Limestone, sandy	2%
			Limestone	77%
			Limestone, Dolomitic	7%
2196.2'	55.8'	Bois Blanc		
			Limestone, sandy	32%
			Limestone	61%
			Limestone, Dolomitic	7%
2252.8'	6'	Oriskany		
			Sandstone	100%
2258.8'	93.5'	Helderburg		
			Limestone, sandy	67%
			Limestone	22%
			Dolomite, limey	11%
2352.3'	37.7'	Bass Island		
			Limestone, sandy	8%
			Limestone	16%
			Dolomite	29%
2390'	180'	G - Unit		
			Limestone, Dolomitic	24%
			Dolomite, Anhydritic	76%
2570'	374.6'	F - A Units[1]		
			Halite/Dolomite Interbedded	100%

[1] F - A Units were not recorded by the FIL.

Table 3 continued

Formation Characteristics of the Study Borehole
(As obtained from Bulk Density and Gamma Ray logs of the study borehole)

DEPTH TO FORMATION TOP	THICKNESS	FORMATION	LITHOLOGY	PERCENTAGE
2944.6'	62.2'	Greenfield Guelph		
			Sandstone	3%
			Limestone, sandy	6%
			Limestone	4%
			Limestone, Dolomitic	58%
			Dolomite, Anhydritic	29%
3006.8'	345.2'	Lockport		
			Limestone, Dolomitic	2%
			Dolomite, Anhydritic	89%
			Shale, limey	9%
3154'	68'	"Newburg"		
			Limestone, Dolomitic	32%
			Dolomite, Anhydritic	68%
3352'	18'	Rochester		
			Dolomite, Anhydritic	13%
			Shale, limey	87%
3376'	24'	Packer Shell		
			Limestone	50%
			Dolomite, Anhydritic	50%
3400'	upper 180'	Clinton		
			Sandstone	32%
			Shale, sandy	22%
			Shale, limey	46%
3568'		Total Depth		

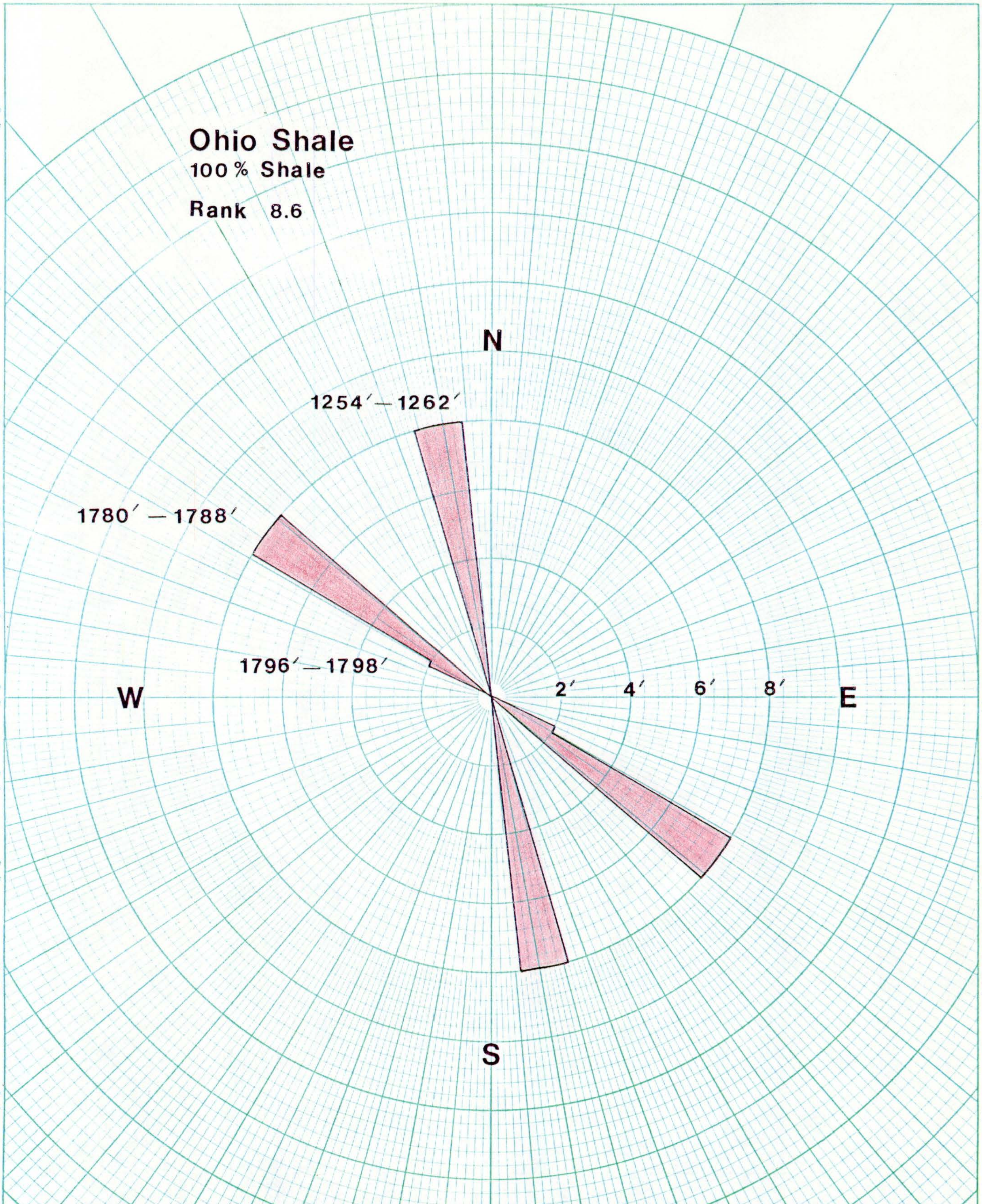

Figure 2

Ohio State University
Matthew Shafer Senior Thesis June 1981

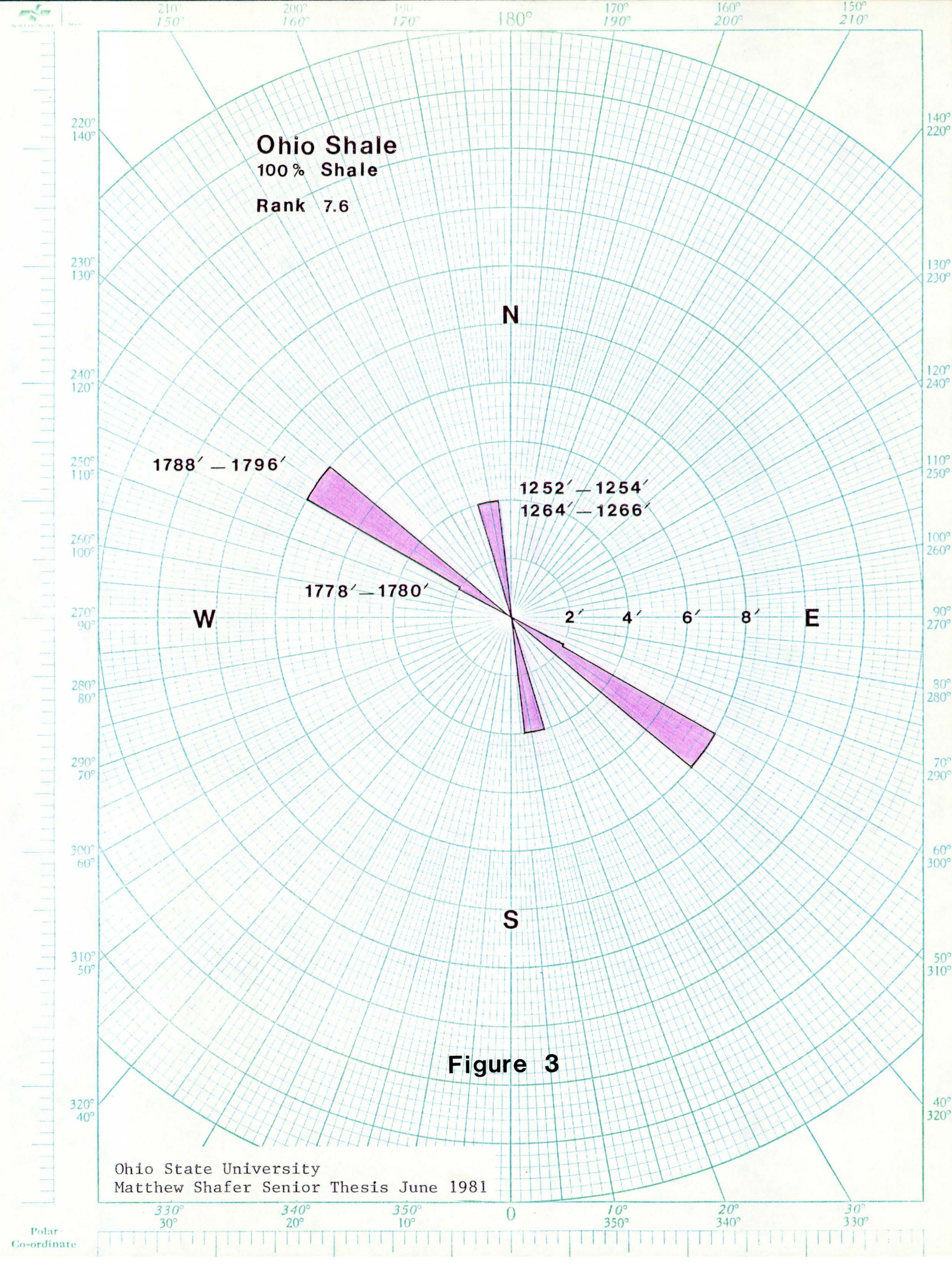

Figure 3

Ohio State University
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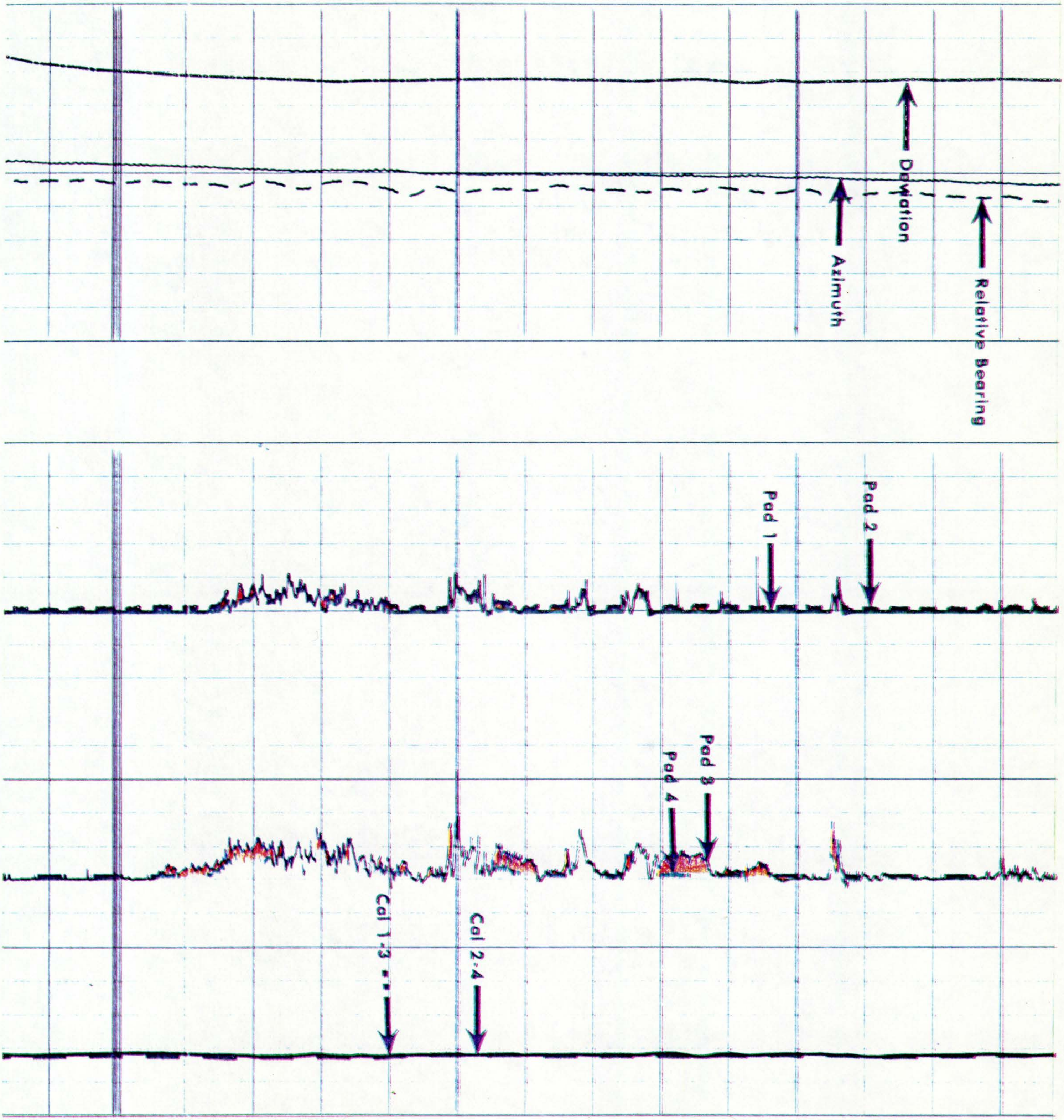

PLATE I

FIL curve identification

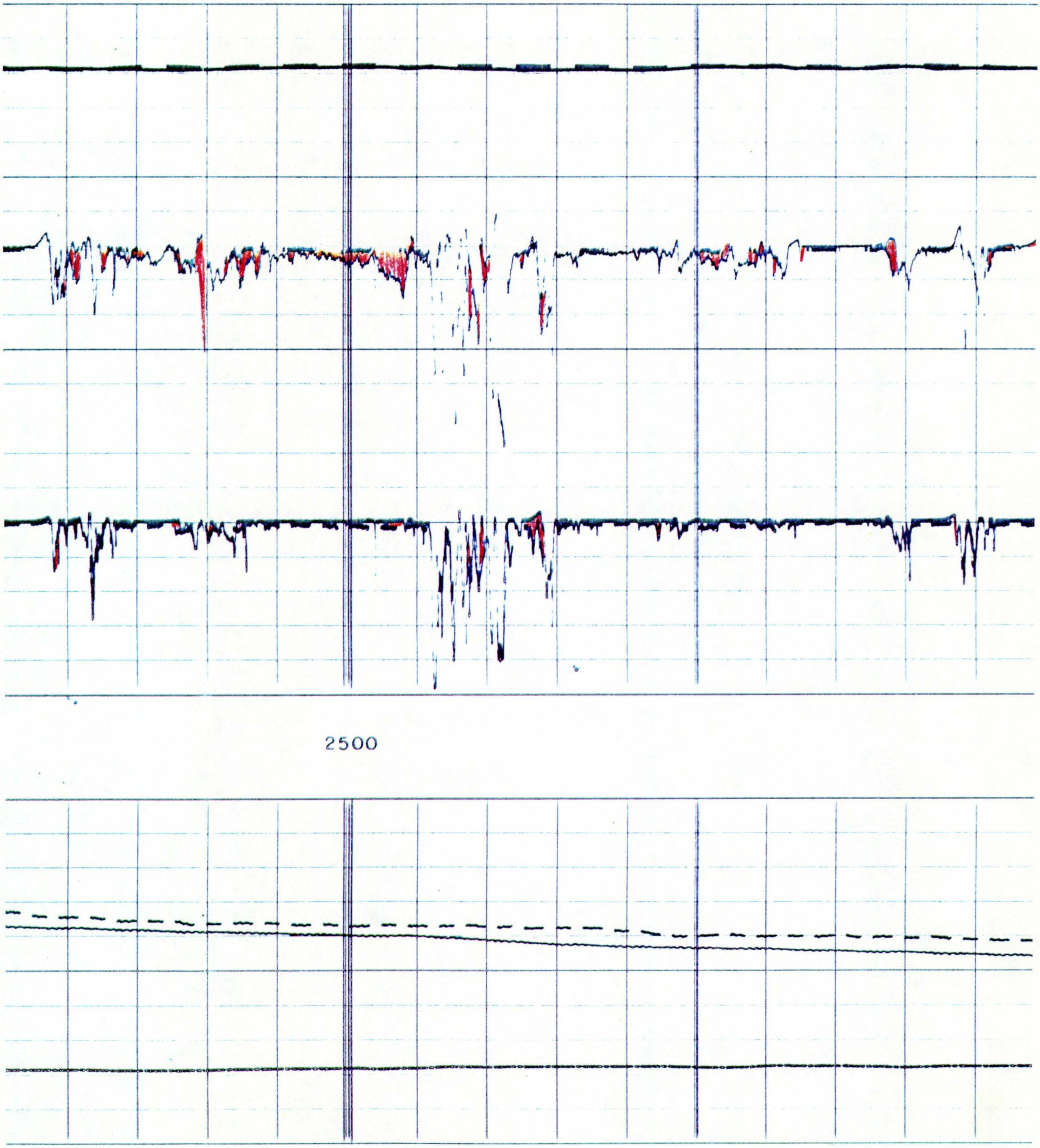

PLATE II

Horizontal fracture and/or
bedding plane activity.